REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE 9-20-01	3. REPORT TYPE AND DATES COVERED Final 11/01/93 – 9/30/01

4. TITLE AND SUBTITLE
The determination of Macro- and Micro-Physical Characteristics of Aerosol Spatial Inhomogeneities

5. FUNDING NUMBERS
N00014-94-1-0064

6. AUTHOR(S)
Kusiel S. Shifrin
Ilia G. Zolotov

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Oregon State University
Corvallis, OR 97331

8. PERFORMING ORGANIZATION REPORT NUMBER
N0034C

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ONR
Ballston Centre Tower One
800 North Quincy St.
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unlimited Public Access

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The present work is concentrated on studying the aerosol spatial and temporal structure in LP MABL with the use of the database of the unique complex Hawaii experiment SEAS (Shoreline Environment Aerosol Study) [1]. By performing a simultaneous analysis of SEAS lidar and nephelometer observations, direct measurements of the aerosol particle size distribution (APSD), and environmental data, and by interpreting the results in terms of the aerosol optical properties, we seek a thorough understanding of the radiative transmittance in LP MABL.

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

Otzet ONR za 2001

The Determination of Macro- and Microphysical Characteristics of Aerosol Spatial Inhomogeneities in the Lower Part of the Marine Atmospheric Boundary Layer from the Backscattered Lidar Signal (the Direct and Inverse Problem)

Kusiel S. Shifrin
College of Oceanic and Atmospheric Sciences
Oregon State University
Oceanography Administration Building 104
Corvallis, OR 97331-5503
phone: (541) 737-2016 fax: (541) 737-2064 email: shifrink@ucs.orst.edu

Ilia G. Zolotov
College of Oceanic and Atmospheric Sciences
Oregon State University
Oceanography Administration Building 104
Corvallis, OR 97331-5503
phone: (541) 737-2016 fax: (541) 737-2064 email: zolotovi@ucs.orst.edu

Award Number: N000149410064

LONG-TERM GOAL

Our long-term goal is to be able to predict the propagating conditions for an electromagnetic signal in the lower part of the marine atmospheric boundary layer (LP MABL). The light scattering and attenuation is strongly affected by the atmospheric aerosol. The latter, in its turn, is strongly dependent on the air humidity, wind, atmospheric turbulence, etc. The relationship between the environmental factors and the aerosol optical properties is quite complicated. This makes the aerosol the least certain component in prediction models of the light transmittance in LP MABL. The essence of our investigation is to develop reliable methods for determining the aerosol macro- and microphysical characteristics in LP MABL.

OBJECTIVE

The present work is concentrated on studying the aerosol spatial and temporal structure in LP MABL with the use of the database of the unique complex Hawaii experiment SEAS (Shoreline Environment Aerosol Study) [1]. By performing a simultaneous analysis of SEAS lidar and nephelometer observations, direct measurements of the aerosol particle size distribution (APSD), and environmental data, and by interpreting the results in terms of the aerosol optical properties, we seek a thorough understanding of the radiative transmittance in LP MABL.

APPROACH

Our approach to the problem was to examine offshore aerosol fields at Hawaii by analyzing and inverting horizontal lidar data and by invoking other SEAS experimental data as a constraint in the inverse problem. The inversion of lidar data into APSD is a substantially incorrect problem. The inversion method of mean ordinates [2,3] deals just with such problems. The method proved its efficiency in our numerical experiments and in the analysis of Hawaii horizontal lidar data [4]. The method, however, was developed for all kinds of marine aerosols, with regard to all possible combinations of aerosol components. This inevitably expanded the parameter intervals of the sought-for solution, thus increasing the error of the most probable solution. When dealing with a specific case, it becomes unnecessary to include into consideration such wide a variety of aerosols. Low-probability solutions can be filtered out by employing additional information on aerosol in LP MABL. It is noteworthy that there is no need for APSD data to cover the whole particle size interval. It is sufficient to have information for the so-called "optically active" interval [2]. It should be also pointed out that when using a constraint on lidar data, the most probable solution may be not as smooth as when using lidar measurements alone.

TASK COMPLETED

We estimated the potentials of the method of mean ordinates combined with an APSD constraint. The work started with a series of numerical experiments. We considered two particle size intervals: 0.1 - 0.5 and 0.1 – 1.0 μm. The experimental error of APSD was set at 100%, 50%, 30%, and 20%. The procedure was as follows. We constructed an ensemble of aerosol models satisfying the lidar- derived attenuation and backscatter. They were considered to be acceptable solutions to the inverse problem. Of these, we chose the models that met the APSD data on a given particle size interval. The model whose ordinates were closest to the mean over this reduced ensemble was designated as the most probable solution. We applied this approach to two two-lidar measurement schemes: (0.55; 10.591) μm and (0.532; 1.064) μm. The latter was consistent with that in the SEAS experiment. We found out that APSD data measured with an error of 100% introduced virtually no improvement into the inversion efficiency. However, an APSD of an accuracy of 50% improved the inversion results by a factor of two.

Fig. 1 shows the retrieval accuracy of APSD from horizontal lidar data for large particles (the "tail" of the particle size distribution) as a function of the experimental error of the constraint. It is seen that the improvement of constraint accuracy beyond 50% only slightly reduces the inversion error. It is noteworthy that the width of the particle size interval for which the constraint data were available is of no practical importance. The constraint for the 0.1 – 0.5 and 0.1 – 1.0 μm intervals has about the same effect. The essential point is for the interval to include a part of the so-called "optically active" range. We mean the range having a major optical effect at a given spectral band. In our case, the optically active particle size interval occurred between 0.22 and 3.0 μm [2].

The employment of an APSD constraint proved to be particularly effective when dealing with non-smooth solutions, most notably for those whose aerosol components appeared as isolated peaks. For such cases, the use of the method of mean ordinates without a constraint could obtain only the general slope of a distribution, and only slightly outline the position of the peaks. We showed earlier [4] that the result could be improved significantly by using an additional pair of lidars at intermediate wavelengths. It turned out that a similar improvement could be achieved by using an APSD constraint of a 70% accuracy. Even when the constraint error is 100%, the ensemble of acceptable solutions narrows significantly as compared with that without constraint. As the experimental error of the constraint decreases, the position of the peaks becomes distinct, as well as their respective heights.

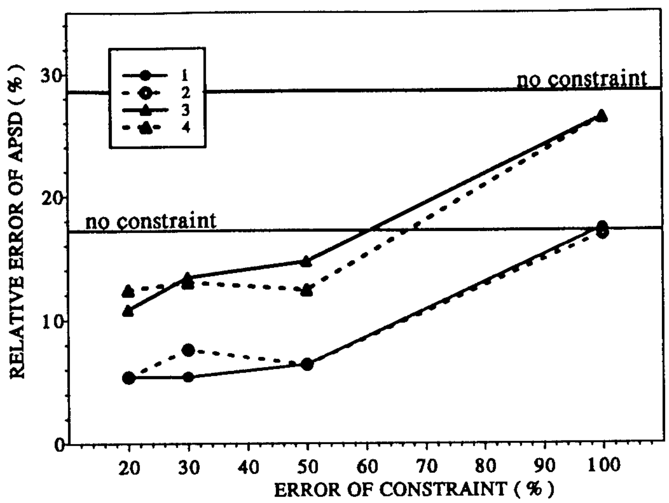

Fig. 1. The error of the retrieval of the APSD "tail" in relation to the error of the constraint (numerical experiments). 1,2, two lidars at 0.55 and 10.591μm; 3,4, two lidars at 0.532 and 1.064 μm; 1,3, APSD constraint for the 0.1-0.5 μm particle size interval; 2,4, APSD constraint for the 0.1-1.0 μm particle size interval [A constraint in a form of APSD of 50% accuracy improves the inversion accuracy by a factor of two].

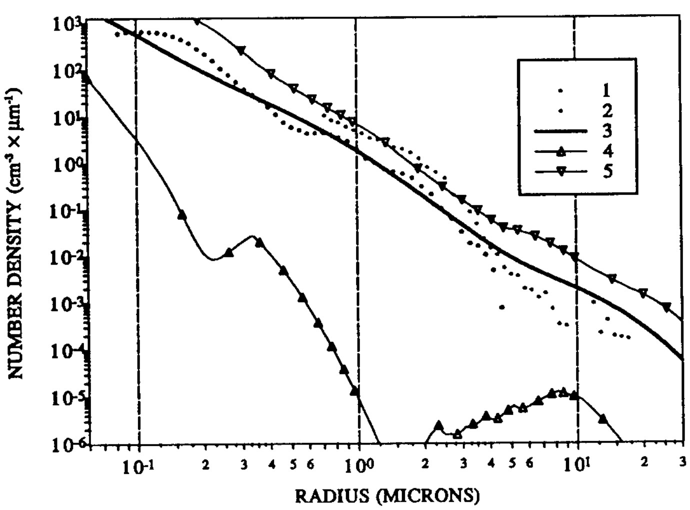

Fig.2. The inversion of the aerosol spectral attenuation into APSD without a constraint. 1, experimental APSD by OPC; 2, experimental APSD by APS; 3, inversion results; 4, minimal ordinates of the ensemble of acceptable solutions; 5, maximum ordinates of the ensemble of acceptable solutions [The inversion results are in a general agreement with the experimental data].

At present we are testing and improving the method of mean ordinates by using the SEAS experimental data. We considered the experimental data for 19h52m, April 22, 2000 [5]. We inverted the aerosol attenuation at λ = 0.532 μm. For the aerosol attenuation, we used $\sigma = 0.056$ km^{-1} nephelometer observations (It was not critical for our purposes which σ to use: lidar or nephelometer-derived one, because the SEAS participants found the agreement between both data sets satisfactory).

The inversion of σ into APSD was performed by the method of mean ordinates. The set of initial models was similar to that constructed in [4]. The experimental error of σ was ±5%. The inversion results are shown on Fig. 2. Curve 3 is the most probable APSD. Curves 4 and 5 represent respectively the minimal and maximum ordinates of APSDs satisfying the value of σ. On the same figure are shown the results of direct APSD measurements that were performed simultaneously with the lidar and nephelometer observations on shore near the lidar site. Curve 1 represents the APSD measured by an optical particle counter (OPC). Curve 2 shows the APSD measured by an aerodynamical particle sizer (APS). It is seen that the inversion results reflect the general shape of APSD as it is outlined by the direct measurements. True, the experimental data are more detailed than the APSD by inversion. Thus, the mode of small particles at 0.2 μm is lacking, although the mode at 1 μm is evident. The mode at 10 μm and beyond is also noticeable. However, in view of the fact that there is a certain difference between the data sets 1 and 2, it is hard to tell which of the experimental details reflect the reality rather than an experimental error.

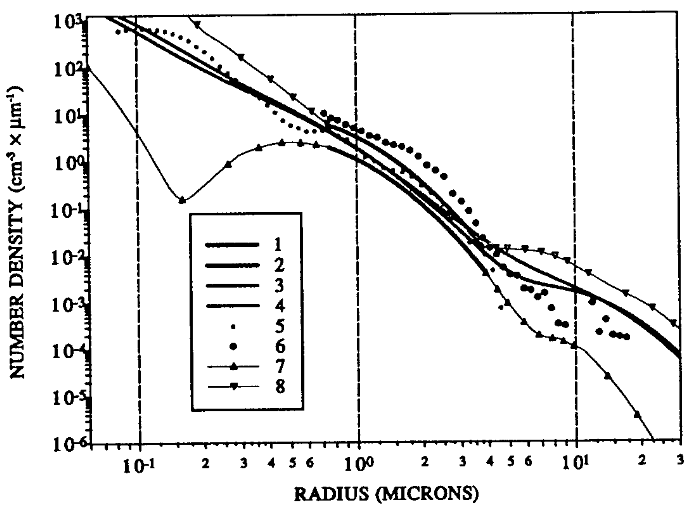

Fig.3. Inversion results with the use of an APSD constraint. 1, the lower limit of constraint at – 50% of the smoothed OPC-derived APSD; 2, the upper limit of constaint at 50% of the smoothed OPC-derived APSD; 3, inversion results with the constraint; 4, inversion results without constraint; 5, experimental APSD by OPC; 6, experimental APSD by APS; 7, minimal ordinates of the ensemble of acceptable solutions; 8, maximum ordinates of the ensemble of acceptable solutions [With the use of the APSD constraint, the inversion results improved noticeably].

Although the most probable solution is quite consistent with the measured APSD, the area of acceptable solutions (bounded by curves 4 and 5) is rather wide. It comes as no surprise, considering the fact that the inversion was performed with a single value of the aerosol spectral attenuation. We examined how the use of a constraint in a form of APSD on some limited particle size interval can narrow the area of acceptable solutions and thus to reduce the inversion error (see Fig. 3). We used the OPC data for the 0.7 – 3.5 μm particle size interval. The direct data were smoothed. The upper and lower limits of the constraint were taken respectively at ± 50% of the smoothed curve. The limiting curves are marked 1 and 2 on Fig. 3. The most probable solution with the constraint is represented by curve 3. For comparison the solution without constraint is shown by curve 6. It is seen that curve 3 better approximates the area of small-sized particles at 0.1 - 0.2 μm than the solution without constraint. The second mode at 1 μm is also revealed more vividly, although the peak is significantly wider than the same portion of APSD as measured by OPC. It is of particular optical importance that the mode of large particles at 10 – 15 μm manifests itself quite clearly.

RESULTS

We tested the method of mean ordinates by inverting the SEAS data for the aerosol spectral attenuation and comparing the inversion results with direct SEAS observations over APSD. The coincidence proved to be satisfactory. An APSD constraint was imposed on the inverse problem. The inversion error was reduced by a factor of two with a constraint of 50% accuracy. The employment of the constraint resulted in revealing a number of APSD details in the area of smaller and very large particles. We have proved that aerosol spatial inhomogeneities can be determined by analyzing the temporal structure of the backscattered lidar signal.

IMPACT/APPLICATION

In the process of analyzing the SEAS horizontal lidar data, we developed a method for retrieving the spatial aerosol structure in LP MABL from the backscattered lidar data [6]. The method is less cumbersome and costly than those now in common use.

TRANSITIONS

Our method of studying the aerosol structure in LP MABL is used by Dr. V.I. Haltrin, Naval Research Laboratory, Ocean Sciences Branch; Dr. Helena Gonzales-Jorge, La Laguna University, Tenerife, Spain; Dr. A. Consortini, University of Florence, Italy; Dr. A. A. Gitelson, University of Nebraska; Dr. A.D. Fedorowskii, Marine Hydrophysical Institute, Ac. Sci. of Ukraine; Dr. J. Lenoble, Grenoble University, France; Dr. O.V. Kopelevich, Institute of Oceanology of the Russian Academy of Sciences.

RELATED PROJECTS

Our method of mean ordinates is being used in our NASA-funded project "The Refinement of the Atmospheric Correction Algorithm for Determining the Marine Chlorophyll Concentration from Space".

REFERENCES

1. Clarke, A., Kapustin, V., Sharma, S., Lienert, B., Porter, J., Moore, K., Hallmark, B., Howell, S., Covert, D., Anderson, T., Doherty, S., Saltzman, E., Jost, P.C., Hynes, A., and Hunt, A., Shoreline environment aerosol study (SEAS), Interim report to ONR, 2000.

2. Shifrin, K.S., and I.G. Zolotov, Information content of the spectral transmittance of the marine atmospheric boundary layer, *Applied Optics, 35*(24), 4835-4842, 1996.

3. Shifrin, K.S., and I.G. Zolotov, A method for retrieving the aerosol particle size distribution from horizontal lidar data, *Applied Optics*, 2001, submitted.

4. Shifrin, K.S., and I.G. Zolotov, The analysis of horizontal lidar data by the method of mean ordinates, Interim report to ONR, 2000, http://pali.soest.hawaii.edu/projects/seas.html

5. Kapustin, V., Private communication, 2001.

6. Shifrin, K.S., B.R. Lienert, J.N. Porter, and S.K. Sharma, The determination of the aerosol spatial structure in the lower part of the marine atmospheric boundary layer from the temporal structure of the backscattered lidar signal, *Applied Optics*, 2001, submitted.

PUBLICATIONS

Shifrin, K.S., and I.G. Zolotov, Spectral attenuation and aerosol particle size distribution, *Applied Optics, 35*(12), 2114-2124, 1996.

Shifrin, K.S., and I.G. Zolotov, Information content of the spectral transmittance of the marine atmospheric boundary layer, *Applied Optics, 35*(24), 4835-4842, 1996.

Shifrin K.C., and I.G. Zolotov, The determination of the aerosol particle- size distribution from simultaneous data on spectral attenuation and the small-angle phase function, *Applied Optics, 36*(24), 6047-6056, 1997.

Shifrin, K.S., R.M. Carlson, and I.G. Zolotov, Retrieval of the aerosol particle size distribution (APSD) in the lower part of the marine atmospheric boundary layer (LP MABL) from horizontal measurements of the atmospheric spectral transmittance, *Proc. SPIE, 3325*, 170-182, 1998.

Levin I.M., and K.S. Shifrin, Potential for determining the sea water absorption coefficient by satellite pulsed lidar, *Remote Sensing Environ., 65*, 105-111, 1998.

Shifrin, K.S., Atmospheric aerosol, methods of analysis. In: *The Encyclopedia of Environmental Analysis and Remediation,* Robert A. Meyers, Ed., v. 1, 446 - 505, John Wiley & Sons, N.Y., 1998.

Osadchy, V.U., K.S. Shifrin, and I.Ya. Gurevich, The airborne identification of oil films at the Caspian Sea surface using CO2 lidar, *Oceanologica Acta 21*(5), 7,1998.

Kokorin, A.M., and K.S. Shifrin, The influence of humidity on the light scattering characteristics of radially inhomogeneous particles, *Journal of Optical Technology, 67*(1), 44-49, 2000.

Shifrin, K.S., and I.G. Zolotov, A method for retrieving the aerosol particle size distribution from horizontal lidar data, *Applied Optics*, 2001, submitted.

Shifrin, K.S., B.R. Lienert, , J.N. Porter, and S.K. Sharma, The determination of the aerosol spatial structure in the lower part of the marine atmospheric boundary layer from the temporal structure of the backscattered lidar signal, *Applied Optics*, 2001, submitted.